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EVOLUTION OF MARKET STRUCTURE IN A DOMINANT FIRM MODEL WITH EXHAUSTIBLE RESOURCES[+]

by

Mukesh Eswaran* and Tracy R. Lewis

Resources Paper No. 77

February 1982

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1. Introduction:

The recent emergence of natural resource cartels like OPEC have prompted economists to study the effects of market structure on exhaustible resource use. The extensive literature on this subject is nicely summarized in Dasgupta and Heal (1979, especially Chpt. 11). Most of this literature ignores the questions of how the supply side of the market evolves over time, and what factors determine the initial distribution of reserves among competing suppliers.[1] For example, it would be interesting to know why some resource markets are more concentrated (in terms of reserve ownership) than others.[2]

Certainly, the geographical distribution of reserves partially determines concentration. Also suppliers can augment their stocks by exploring for new sources or by acquiring reserves from other firms. Reserve acquisition of this type has occurred occasionally in markets for copper, bauxite, and molybdenum.[3] The structure of some of these markets has evolved in this way. Initially, large reserves are discovered by one or a few suppliers who become leading firm(s) in the industry. These firms maintain a dominant position by supplementing their stock through exploration and acquisition of reserves from smaller suppliers. In the long run a dominant firm (cartel)--competitive fringe industry structure results from this process.

This description of how some resource markets evolve over time suggests several questions to us. Are there "first in" advantages in exhaustible resource industries; is there an incentive for a dominant firm to maintain and enhance its position in the market? Is there a natural or stable size for a dominant firm? To what extent can a cartel prevent competition from fringe producers by pre-emptive exploration and acquisition?[4]

In this paper we try to answer these questions by looking at a simple dominant firm-competitive fringe model of a resource industry where the ownership of reserves is endogenously determined. We assume that the dominant firm or cartel initially controls a significant portion of known reserves. The industry also consists of a group of competitive fringe suppliers who each own a small fraction of the available stock. We assume that there is some additional stock contained in separate "pools" (locations) that have not yet been discovered and claimed. The reserves in a given pool are obtained by discovering the pool first. Resource exploration is assumed to be a deterministic process so that a pool is claimed by the firm spending the most on exploration. An alternative assumption is that all of the resource has been discovered, but that some of it is owned by the government. Firms can augment their supplies by bidding the most for new reserves as they are auctioned off by the government.

Formally, we model resource supply as two sequential discrete processes. First, firms acquire resource stocks through competitive exploration and development. Second, firms extract and sell resources from their reserves once the ownership of the stock is determined. Logically, we must assume that firms can predict the outcome of the second post acquisition phase of supply in order to form expectations about the profitability of acquiring resource stocks during the initial supply phase.[5] In particular we assume that during the extraction phase the dominant firm acts as an intertemporal Stackelberg price leader. It announces a time path of prices, assuming that fringe producers react by choosing a profit maximizing extraction program. This process, which is characterized in Salant (1976, 1979), Lewis and Schmalensee (1980, 1982), and Ulph and Folie (1980) results in a well defined extraction equilibrium. We assume that firms can calculate the resulting equilibrium level of profits, for all allocations of initial reserves between the dominant firm and the competitive fringe. This information is then used by firms to determine the optimal expenditure for acquiring reserves during the exploration phase of supply. We note that this formulation ignores the possibility that exploration may be uncertain, and that firms may explore and extract simultaneously. This is done to maintain tractibility, but we are not convinced that the predictive content of our model would change significantly if these complications were introduced.

Our analysis begins in section 2 where we characterize extraction equilibria for the dominant firm-competitive fringe model in terms of the initial reserves controlled by the dominant firm. This information is used in section 3 to analyse the reserve acquisition process. We assume that the resource is distributed in discrete amounts among N distinct pools. Firms acquire the reserves contained in a particular pool by outspending their rivals in exploration. Alternatively, reserves--already known to exist--are acquired through the process of competitive bidding. We are interested in determining the dominant firm's ability to limit competition from the fringe by pre-emptive discovery of new reserves. We find that in some instances, fringe suppliers who manage to acquire some of the stock benefit from higher prices brought about by the presence of the dominant firm.[6] This free-rider effect reduces the dominant firm's incentives to outspend its fringe rivals in exploration. We demonstrate that the prospects for pre-emption are best when the resource is concentrated in large amounts in a small number of pools. This is because the cost to the dominant firm of acquiring reserves increases when the available resource is distributed in many separate pools.

There are other instances, described by Ulph and Folie (1980), when fringe supplier profits fall as the dominant firm acquires additional reserves. In this case we demonstrate the profitability of complete pre-emptive discovery/acquisition of all available reserves by the dominant firm.

Section 4, examines pre-exploration behavior of the dominant firm which reduces the eventual costs of reserve acquisition. The dominant firm can influence the value of undiscovered resources by signing long term contracts with consumers prior to exploration or acquisition of reserves. For example, the value of reserves to the fringe may decline if the cartel commits itself to selling additional resources at lower prices during initial periods of the extraction horizon. We show that this policy is effective because it decreases the costs of resource acquisition more than it reduces the value of new reserves to the dominant firm. By depressing resource prices, the dominant firm reduces the free-rider benefits accruing to fringe producers, and it makes pre-emptive reserve acquisition more attractive. This is illustrated with an example where we show that complete pre-emption of available reserves is made profitable by deflating resource prices. Also we note that there is empirical support for this behavior as it has been suggested that AMAX, the leading molybdenum producer, has depressed current selling prices to decrease the future costs of acquiring reserves.[7]

The analysis is concluded in section 5 with a summary of results and suggestions for further work.

2. The Price-Leadership Extraction Model:

2.a Assumptions

Following Salant (1976) we consider an exhaustible resource market where consumers purchase supplies at the same price from independent firms. For now we assume that the initial resource stock is distributed between a dominant firm or cartel, and a group of fringe suppliers. The question of how this distribution is determined is the subject of sections 3 and 4. The cartel sets current and future prices in the market by signing binding long term service contracts with consumers, to supply quantities of the resource at specified prices.[8] Fringe producers choose a sales path to maximize discounted profits taking prices as given in each period. Hence, the cartel chooses a price path, supported by its sales, to maximize discounted profits, subject to the supply response of the fringe.

Note that this is a Stackelberg price leader-follower formulation, whereas the Salant (1976) model assumes Cournot-Nash behavior for all firms. Under conditions to be specified below, the two approaches are equivalent yielding the same price and quantity paths in equilibrium (see Lewis and Schmalensee (1982)).

Let $q(t)$ be total market sales and $q^c(t)$ and $q^f(t)$ be the sales of the cartel and competitive fringe, respectively. Following Salant (1976), we assume that there is a stationary inverse demand function $p(q)$, with $p'(q) < 0$ and a finite choke price $\bar{P}$, and that the coefficient of price elasticity $e(q) = -dq/dp\ /(p/q)$ is strictly decreasing in q.

In much of our analysis, zero marginal extraction costs are assumed. (The introduction of constant positive marginal extraction costs does not change our results). However, the assumption that all producers face the same constant extraction costs is not innocuous as demonstrated by Ulph and Folie (1980). The implications of marginal extraction costs varying across different resource deposits is examined in section 3.

Finally, an important assumption of our model is that the cartel can credibly commit itself to support the price it announces for each time period. This is equivalent to requiring the existence of a futures market for the resource, where extractors can contract with consumers for current and future deliveries of the resource. In the absence of complete futures markets, the ability of the cartel to commit itself to a stream of future prices is diminished. In fact, in this case the cartel may profitably deceive fringe suppliers by announcing price paths that it knows it will want to change later on (see Lewis and Schmalensee (1982) and Newberry (1981)).[9] The problem of characterizing equilibria in the absence of futures markets is not our main concern in this paper, so that we will not deal with it here except for a brief discussion in section 5.

2.b Properties of Equilibria:

In equilibrium, the cartel announces a time path for prices that maximizes its discounted profit subject to the profit maximizing response of the price-taking fringe. Taking the response of the fringe suppliers as given, straightforward maximization of cartel profits yields the necessary conditions (2.1)-(2.4) for a Stackelberg equilibrium.[10]

$$e^{-rt}MR^c(q^c,q^f) \equiv e^{-rt}[p(q^c+q^f) + \frac{dp}{dq}q^c] \equiv MR_o^c \tag{2.1}$$

$$\int_0^T q^c(t)dt = I^c \tag{2.2}$$

$$e^{-rt}p(q^c+q^f) = p_o \text{ whenever } q^f > 0 \tag{2.3}$$

$$\int_0^S q^f(t)dt = I^f \tag{2.4}$$

Equation (2.3) is an equilibrium arbitrage condition that holds whenever price-taking fringe suppliers produce. Given this condition, the cartel maximizes profits by equating discounted marginal revenue (calculated along its excess demand curve) across all time periods as indicated in equation (2.1). The resource constraints are given by (2.2) and (2.4), where T and S denote the extraction horizon b, and I^c and I^f represent the initial reserves of the cartel and competitive fringe, respectively.

Salant (1976) shows that the intertemporal equilibria described by the equations above consists of two phases. Initially, both the competitive fringe and the cartel operate during a phase in which price rises at the rate of interest. Eventually, at time $S < T$, fringe supplies are exhausted and the entire market is left to the cartel which then operates as a monopoly with $\dot{p}/p < r$.[11]

Lewis and Schmalensee (1980) analyse the effects on equilibria of changes in fringe and cartel initial resource endowments. These results are summarized here, for use in sections 3 and 4. Let $p_o(I^c,I^f)$ and $MR_o^c(I^c,I^f)$ (defined by equations (2.3) and (2.1) respectively) denote the constant discounted price and marginal revenue accruing to fringe suppliers and the cartel, respectively, in market equilibrium, and let $W^c(I^c,I^f)$ and $W^f(I^c,I^f)$ represent total discounted profits earned by the cartel and competitive fringe sector. Some of the comparative static effects of variations in the initial reserve levels are given below, (see Lewis and Schmalensee (1980) pp 140-142, 151-153 for details).

$$dW^c/dI^c = MR_o^c \quad , \quad dW^f/dI^f = p^o \tag{2.5}$$

$$dMR_o^c/dI^i \quad , \quad dp_o/dI^i < 0 \quad \text{for } i = c,f \tag{2.6}$$

$$dW^c/dI^c - dW^c/dI^f = p_o,\ dp_o/dI^c - dp_o/dI^f > 0 \tag{2.7}$$

$$d(W^c+W^f)/dI^c - d(W^c+W^f)/dI^f > 0 \tag{2.8}$$

According to (2.5) and (2.6), the marginal value of reserves to the cartel and competitive fringe represented by MR_o^c and p_o, respectively, decline with greater initial reserves. Total and average cartel profits increase, as reserves shift from the competitive fringe to the cartel, as indicated by the first part of eq. (2.7). This occurs because the cartel simultaneously obtains more of the resource, and reduces the reserves of rival suppliers. The second part of equation (2.7) implies that fringe suppliers who continue to hold resources also benefit by a shift in reserves from the fringe sector to the cartel. This is the "free-rider" effect we mentioned above. Equation (2.8) shows that total industry profits increase with the relative size of the cartel.

3. Dominant Firm Pre-emption

3.a A Case Where Fringe Producers Benefit from the Presence of the Cartel

We now consider the struggle between the cartel and the competitive fringe to acquire initial reserves. For simplicity, suppose that the available resource stock is a fixed known amount, I. Initially, the cartel controls $I^c > 0$ of the stock, the fringe collectively owns $I^f \geq 0$, and there is a residual, $D=I-I^c-I^f > 0$ left to be claimed and discovered.[12] D is equally divided among N distinct sources or "pools" each containing D/N of the stock. (Alternatively, we can imagine that D is initially controlled by N equal sized fringe suppliers, and that the dominant firm may increase its stock by buying out some of these producers).

The stock contained in a particular pool is captured by the firm which spends the most in finding that source. There is simultaneous and unrestricted competition for each of the N pools. This means that the eventual winner of each pool must spend at least the maximum amount that the pool would be worth to some other producer.

Let us calculate the net return to the cartel of acquiring some amount $E < D$ of the residual reserves. Assume that the stock in each pool is $\Delta = D/N$. Assuming E is divisible by Δ, the cartel must acquire $N_E = E/\Delta$ pools. Consider a fringe supplier who competes for one of the N_E pools. If he should capture that pool, and the cartel acquires the other N_E-1 pools, the fringe producer earns extraction profits equal to

$$\Delta p_o(I^c+(N_E-1)\Delta) \tag{3.1}$$

where p_o is expressed as a function of the reserves owned by the cartel. Equation (3.1) represents the value of each pool to a potential fringe supplier. In order for the cartel to capture all N_E pools, it must spend at least

$$N_E\Delta p_o(I^c+(N_E-1)\Delta) = E\, p_o(I^c+E-\Delta) \tag{3.2}$$

where we have used $N_E\Delta = E$ in deriving (3.2). The cartel's net return of acquiring E reserves, assuming the stock per pool is Δ, denoted by $R_\Delta(E)$, is equal to

$$R_\Delta(E) = W^c(I^c+E) - W^c(I^c) - p_o(I^c+E-\Delta)E \tag{3.3}$$

where W^c is written as a function of the cartel reserves. A necessary condition for the acquisition to be profitable is that $R_\Delta(E) > 0$. We can rewrite $W^c(I^c+E)$ as

$$W^c(I^c+E) = \int_{I^c}^{I^c+E} W^{c\prime}(z)dz + W^c(I^c) \tag{3.4}$$

Substituting the expression in (2.7) for $W^{c'}$ into (3.4) we obtain

$$W^c(I^c+E) - W^c(I^c) = \int_{I^c}^{I^c+E} p_o(I^c+z)dz \tag{3.5}$$

According to (2.7) p_o is strictly increasing. Hence there exists a $\hat{z}\varepsilon(0,E)$ such that

$$W^c(I^c+E) - W^c(I^c) = p_o(I^c+\hat{z})E \tag{3.6}$$

Substituting this expression into (3.3) we obtain

$$R_\Delta(E) = (p_o(I^c+\hat{z}) - p^o(I^c+E-\Delta))E \tag{3.7}$$

Eq. (3.7) implies that the sign of $R_\Delta(E)$ depends on the size of Δ. If Δ is large, so that the residual stock is concentrated in a few pools, then acquisition by the cartel is profitable. Also some amount of acquisition, for example $E = \Delta$, is profitable for any Δ. But for a given E, if Δ is sufficiently small then $R_\Delta(E)$ is negative, and the acquisition of E reserves is not feasible. The reason for this is that each additional pool that is captured by a fringe producer reduces the value of reserves to that producer as well as to the rest of fringe. But if the amount contained in each pool is small, then the decrease in the value of reserves due to a transfer of one pool from the cartel to the fringe is small. This enhances the incentive for fringe suppliers to acquire new reserves, which is reflected in a higher average acquisition price $p_o(I_c+E-\Delta)$ to the cartel.[13]

In general, it does not seem possible to say much about the size of the optimal acquisition and how it depends on Δ. While we do know that the profitability of any acquisition varies directly with average pool size, it does not seem possible to analytically show, for example, that the optimal amount to acquire increases with Δ. Part of the ambiguity arises because of integer problems associated with the discrete nature of our problem. The optimal acquisition, E^*, satisfies the condition

$$R_\Delta(E^*+\Delta) - R_\Delta(E^*) = \int_{E^*}^{E^*+\Delta} R'_\Delta(x)dx \leq 0 \qquad (3.8)$$

assuming $E^* < D$. Differentiating eq. (3.3) with respect to E and using eq. (2.7) we obtain,

$$R_\Delta'(E) = W^{c'}(I^c+E) - p_o'(I^c+E-\Delta)E - p_o(I^c+E-\Delta) \qquad (3.9)$$

$$= p_o(I^c+E) - p_o(I^c+E-\Delta) - p_o'(I^c+E-\Delta)E$$

Eq. (3.9) implies that $R_\Delta'(E) < 0$ for $E > \Delta$ when p_o is a concave (or linear) function of cartel reserves. This together with eq. (3.8) imply that $E^*=\Delta$ when $p_o'' \leq 0$. In this case the degree of pre-emptive acquisition by the cartel is quite limited. When p_o is convex the optimal acquisition is potentially greater than Δ.

An example: Typically, the sign of p_o'' can only be determined by computing the equilibrium for the post-acquisition game. We have done this for a linear demand example where

$$P(Q) = 10 - Q$$

and the total available resource stock is 30 units.[14] Extraction costs are zero, and the discount rate $r = .10$. In Fig. 1 we have graphed p_o, the present value price of the resource in the first phase of the equilibrium, as a function of amount of reserves held by the cartel at time zero. As the graph indicates, p_o is increasing and strictly convex in the amount of resource held by the cartel.

In Table 1 we tabulate the present value profits to the cartel and fringe for a range of possible configurations of the final reserve holdings. Also listed are the present value prices in the first phase of the Stackelberg equilibrium. Using this information and equation (3.3) it is possible to compute the returns to the cartel of pre-empting an amount E of the resource, given Δ and some initial configuration of reserve holdings. For purposes of illustration we assume that the fringe and cartel initially hold 10 and 16 units of the resource and that an additional amount of 4 units remains to be recovered, (i.e., $I^f = 10$, $I^c = 16$ and $D = 4$). In Table 2 we present the returns to the cartel of pre-empting amounts, E, of the additional resource for various assumed values of Δ. (The amount E must, of course, be a multiple of Δ).

Table 2 reveals that while the returns to the cartel of pre-empting an amount equal to 2Δ are positive, the present value profits of the cartel, net of acquisition costs, are maximized for E = Δ. This appears to be true irrespective of the distribution of the initial reserves between the fringe and cartel and of the size of D. Hence at least for this example, the profitability and extent of pre-emptive acquisition is quite limited. In section 4 we see how these results are modified when the cartel can deflate resources prices to decrease acquisition costs.

3.b Acquisitions by the Fringe

It is interesting to enquire if a fringe producer can profitably buy reserves from the cartel. Suppose a fringe supplier contemplates purchasing F reserves from the cartel who initially owns stock I^c. The acquisition by the fringe firm will only be profitable if

$$P_o(I^c-F)F \geq W^c(I^c) - W^c(I^c-F) \qquad (3.10)$$

Following the analysis of equations (3.4) - (3.5) we can rewrite (3.10) as

$$p_o(I^c-F)F \geq p_o(z)F \quad ; \quad z \in (I^c-F,\ I^c) \tag{3.11}$$

Since p_o is strictly increasing the condition in (3.11) is always violated. Hence, at least for this case, the cartel will never divest itself of resource holdings. In section 4 we examine a case in which this conclusion is reversed.

3.c A Case Where Fringe Suppliers are Harmed by the Presence of the Cartel

Ulph and Folie (1980) have constructed a case where the competitive fringe owners of reserves are harmed by the presence of the cartel. They assume that the dominant firm initially owns I^c reserves that can be extracted costlessly. Collectively, the fringe controls a smaller amount of reserves I^f, which can be extracted at a unit cost c. They show that when I^f is sufficiently small and c is sufficiently large, that the equilibrium consists of an initial phase during which the cartel produces, followed by a second phase during which the cartel and fringe both produce. In addition, the discounted net price received by fringe producers, p_o, decreased as the cartel increases its reserve holdings, i.e., $p_o'(I^c) < 0$.[15]

Under these conditions pre-emptive reserve acquisition is always profitable for the cartel. To see this, suppose that the cartel begins with I^c reserves and assume that there is an additional stock of D still available. It is easy to show, that total industry profits increase as total reserves controlled by the cartel increase. Hence, for $E < D$

$$\begin{aligned} W^c(I^c+E) + p_o(I^c+E)(\bar{I}-I^c-E) &> W^c(I^c+E-\Delta) \\ &\quad + p_o(I^c+E-\Delta)(\bar{I}-I^c-E+\Delta) \end{aligned} \tag{3.12}$$

where $\overline{I}$ is the total resource stock, and $\overline{I}-I^c-E$ is the stock held by the fringe, assuming the cartel controls I^c+E of the resource. Since by assumption p_o is a decreasing function equation (3.12) implies

$$W^c(I^c+E) > W^c(I^c+E-\Delta) + p_o(I^c+E-\Delta)\Delta \qquad (3.13)$$

Suppose the cartel has acquired E-Δ reserves. Then eq. (3.3) implies that the net increase in profits obtained by capturing an additional pool is given by

$$R_\Delta(E) - R_\Delta(E-\Delta) = W^c(I^c+E) - W^c(I^c+E-\Delta) - [p_o(I^c+E-\Delta)(E) - p_o(I^c+E-2\Delta)(E-\Delta)] \qquad (3.14)$$

where the expression in square brackets represents the increase in acquisition costs. Since p_o is a decreasing function we can use (3.14) to show

$$R_\Delta(E) - R_\Delta(E-\Delta) > W^c(I^c+E) - W^c(I^c+E-\Delta) - p^o(I^c+E)\Delta \qquad (3.15)$$

It follows from equations (3.15) and (3.13) that $R_\Delta(E+\Delta) - R_\Delta(E) > 0$, so that the incremental return to acquiring additional reserves is positive. Hence, any situation in which the fringe holds reserves is unstable because there is an incentive for the fringe members to sell out to the dominant firm. In fact, fringe suppliers who hold on to their stock are made worse off in the long run.[16]

4. Lowering Prices and Pre Acquisition Behavior:

Let's return to our original model where there are zero marginal extraction costs associated with all reserves. Suppose that the cartel decides to acquire $E \leq D$ reserves. We know that the reserve acquisition price, p_o, is strictly increasing in the amount of the stock held by the cartel. So one way for the cartel to reduce this price would be for it to divest itself of some fraction of its resource stock. For example, the cartel could enter into future contracts with fringe suppliers agreeing to sell them some amount Q of its extracted resource over time at competitive market prices. This would mean that an additional Q reserves would not be controlled by fringe suppliers so that the competitive price for reserves would become $p_o(I^c+E-Q)$. Alternatively, the cartel could sign futures contracts to sell an extra Q units to consumers at competitive prices, $p_o(I^c+E-Q)$. In either case, this commitment to sell resources at deflated prices would decrease the value of acquiring additional reserves to the fringe. Of course in the process of deflating prices, the cartel would also be depreciating the value of its own reserves. However, it is possible to show, that on balance, the decrease in acquisition costs would outweigh the decrease in cartel reserve value for small Q. Let

$$V(E,Q) = W^c(I^c+E-Q) + Qp_o(I^c+E-Q) - Ep_o(I^c+E-\Delta-Q) - W^c(I^c) \tag{4.1}$$

be the return to the cartel of acquiring E reserves through exploration or bidding, given that Q units of the resource are to be sold at the competitive present value price, $p_o(I^c+E-Q)$. The partial derivative of V(E,Q) with respect to Q is given by

$$\frac{dV}{dQ}(E,Q) = -Qp'_o(I^c+E-Q) + Ep'_o(I^c+E-\Delta-Q) \tag{4.2}$$

where we have used (2.7) to obtain the right hand side of (4.2). Evaluating (4.2) at Q = 0, it follows that

$$\frac{dV}{dQ}(E,0) > 0 \tag{4.3}$$

Thus, given E, it is profitable for the cartel to commit at least some amount of the resource to be sold at deflated prices. This is warranted because of a reduction in the acquisition price faced by the dominant firm. On the other hand, evaluating (4.2) at any $Q \geqslant E$ we obtain

$$\frac{dV}{dQ}(E,Q \geqslant E) < 0 \tag{4.4}$$

if the initial price p_o is convex in its argument -- which it is when the demand function is linear for example. In such cases, it is never optimal for the cartel to commit all of or more than the amount pre-empted to be sold at deflated prices; the benefits of lower acquisition costs are more than offset by the lower price received for the resource when ownership is transferred to the fringe.

The profitability of depressing the acquisition price by selling part of the resource at competitive prices will, in general, affect the optimal amount E^* of the resource that the cartel pre-empts. Given E, let Q(E) denote the optimal quantity of the resource to sell at competitive prices, i.e., Q(E) solves

$$\max_Q V(E,Q) \tag{4.5}$$

Substituting for Q(E) into (4.1) and totally differentiating with respect to E yields, upon using the envelope theorem,

$$\frac{dV}{dE}(E,Q(E)) = W'^c(I^c+E-Q) + Qp'_o(I^c+E-Q) - p_o(I^c+E-\Delta-Q)$$
$$-Ep'_o(I^c+E-\Delta-Q)$$

Upon invoking (2.7) and using the first order condition for (4.5) the above expression reduces to

$$\frac{dV}{dE}(E,Q(E)) = p_o(I^c+E-Q) - p_o(I^c+E-\Delta-Q) > 0 \tag{4.6}$$

since p_o is increasing in its argument. It follows from eq. (4.6) that for $E < D$

$$V(E+\Delta,Q(E+\Delta)) - V(E,Q(E)) = \int_E^{E+\Delta} \frac{dV}{dz}(z,Q(z))dz > 0$$

so that complete pre-emptive acquisition of all D available reserves if profitable.

The above result is verified in the numerical example for the linear demand case introduced in Section 3. The return function V(E,Q) is graphed in Figure 2 for various values of E, assuming $I^c=16$, $I^f=10$, $p=4$ and $\Delta=1$ (all the information required to construct Fig. 2 is contained in Table 1).

According to the Figure, V(E,Q) is maximized at E=D=4, i.e., cartel profits are maximized by complete pre-emption. In the previous section we saw that when Q=0, the cartel optimally pre-empts $E=\Delta=1$. Thus, the cartel's strategy of divesting part of its reserves at competitive prices not only enhances the profitability of pre-emption but it also dramatically increases the amount acquired.

Consumers also benefit by the cartel's strategy of deflating prices. From Figure 2 we see that when E=4, $Q(E) \simeq 3.6$. In this case it is as if $I^f+Q = 13.6$ units of the resource are being sold by competitive fringe producers. On the other hand, when Q=0, and E=1 as in the example of Section 3, then $I^f+3 = 13$ units of the resource are competitively controlled. Hence, present value competitive price p_o is lower, and consumers are better off when the cartel is able to depress prices.[17]

In fact, when p_o is a linear function of cartel reserves, equation (4.2) implies that Q(E) = E. It is still profitable for the cartel to pre-empt all available reserves, (i.e., E*=D), but it is as if I^f+D units of the resource are being sold by competitive producers. In this case, the equilibrium price path for the resource is not affected by the pre-emptive behavior of the cartel.

5. Summary:

In this paper we attempted to endogenize the reserve-acquiring process. Our motivation for doing this is to rationalize the various patterns of resource ownership that one observes in different industries. It seems peculiar to us that some resource markets are relatively concentrated while others like the coal market are not. We try to explain these differences by looking at the incentives for dominant firms to pre-empt rival competition by capturing additional stocks. We find that the ability of a cartel to monopolize the market depends on the extent to which fringe producers benefit by the presence of the cartel,[18] the degree of concentration of new reserves in separate locations and the ability of the cartel to control long run prices.

Two primary conclusions emerge from our analysis. First, even though total industry profits increase with concentration, it is not always possible for large firms to completely monopolize the market by bidding away all the resources from smaller fringe suppliers. Second, the dominant firm may voluntarily commit itself and the rest of the industry to charging lower prices for the resource in order to depress the value of new reserves to the fringe. This strategy makes it feasible and optimal -- at least in some cases -- for the cartel to pre-empt all of any new reserves that might become available through discovery or bidding.

There are several possible extensions of our analysis. It is conceivable that one could study the intertemporal stability of cartels in resource markets with our model. There has been a lot of informal discussion of cartel stability particularly with regard to the world oil market, and the long run viability of OPEC. One could perhaps apply some of the recent results of d'Aspremont et al (1981) and Donsimoni (1981) on cartel stability in static markets to our model in order to study dynamic stability questions.

A second extension of our model would be to allow exploration and extraction to occur simultaneously as in the interesting analysis of Pindyck (1978). In this case, exploration would become a real time process. Firms would need to discover new stocks in time to replenish their reserves as they were depleted by extraction. Inefficiencies in exploration might occur because there would be incentives for suppliers to explore more rapidly in order to be the first to discover a given resource deposit.

A third extension of the model would be to examine other intertemporal equilibria, and equilibria for other market structures. For example, we might analyse reserve acquisition, when complete futures markets for the resource did not exist. In this case, it would not be possible for firms to commit themselves to an entire time path of supply. This would involve investigating the so-called closed loop equilibria which have been studied recently by Newberry (1980), Eswaran and Lewis (1982) and Reinganum and Stokey (1981). We might also study other structures besides the dominant firm-competitive fringe one.

Footnotes

1. One notable exception is the interesting analysis by Salant *et al* (1980).
2. The issue of how one measures concentration in resource markets, is itself an interesting problem. Should one use figures on current *stocks* or current *extraction* to compute concentration measures? This and related questions are discussed in Slade (1981) and Lewis and Schmalensee (1979).
3. For example, see "Molybdenum: Outlook Remains Good as New Mine Properties are Sought," March (1980) *Engineering and Mining Journal*, pp 99-103
4. The term "pre-emptive" is borrowed from the thought-provoking papers by Eaton and Lipsey (1977) and Gilbert and Newberry (1981).
5. The logical necessity of this has been emphasized by Dixit (1980) in a different context.
6. Similarly, free=rider effects have been noted in discussions of cartel stability, see Stigler (1964), and firm takeovers; see Grossman and Hart (1980).
7. For example, see *Molybdenum* May (1979) U.S. Department of the Interior
8. Long term service contracts are common in domestic resource industries where they can be enforced at low cost. In international markets, like the world oil market, long term agreements are less common because of the difficulty of enforcing contracts between different nationals.
9. Also see Kydland and Prescott (1977) for a discussion of dynamic inconsistency in leader-follower situations.
10. These are equivalent to eq. (1) - (4) in Salant (1976). Henceforth, time arguments are deleted where no confusion exists.
11. Under different conditions, the order of production may be reversed. Lewis and Schmalensee (1980) show that there is an initial phase when only the cartel produces if $dE(Q)/dQ > 0$ along the market demand curve.

Ulph and Folie (1980) examine the effect of introducing different, but constant, marginal extraction costs on the order of production between the fringe and cartel.

12. The process by which $\bar{I}^c$ and $\bar{I}^f$ are determined will not concern us here.
13. It is interesting to note that a similar result has been noted by Grossman and Hart (1980) in their analysis of firm takeovers. They show that takeover bids may not succeed with numerous small stock holders because of free-rider effects.
14. Details of the calculation are available from the authors.
15. The Ulph and Folie model assumes Cournot-Nash behavior. However, as in the Salant model, it can be demonstrated that the Stackelberg and Cournot-Nash equilibria coincide.
16. This phenomena is similar to the "turning" effect described by Schelling (1960). There, racially mixed neighborhoods are inherently unstable because neighbors of different race are not compatible with each other. Thus, one group is likely to buy out the other, until the neighborhood becomes homogenous.
17. Lewis and Schmalensee (1980, p 151-153) show that consumer surplus increases with the amount of reserves controlled by the fringe.
18. If the demand function were of constant elasticity, for example, and extraction costs zero for both the cartel and the fringe, the latter does not benefit from the formation of a cartel. As is well known, the Stackelberg equilibrium coincides with the competitive equilibrium in this case and is independent of the reserve distribution. In this case, the final distribution of reserves is indeterminate since the returns to both the cartel and the fringe of acquiring additional reserves

are the same. However, the final distribution of reserves has little relevance in this situation since all possible reserve distributions lead to socially optimal outcomes.

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Table 1

Reserves		Present Value Profits		Present Value Price, p_o
Fringe	Cartel	Fringe	Cartel	
10.0	20.0	45.93	85.20	4.59
10.2	19.8	46.73	84.28	4.58
10.4	19.6	47.52	83.36	4.57
10.6	19.4	48.32	82.45	4.56
10.8	19.2	49.11	81.54	4.55
11.0	19.0	49.90	80.63	4.54
11.2	18.8	50.69	79.72	4.53
11.4	18.6	51.48	78.82	4.52
11.6	18.4	52.26	77.92	4.51
11.8	18.2	53.05	77.02	4.50
12.0	18.0	53.83	76.12	4.49
12.2	17.8	54.61	75.22	4.48
12.4	17.6	55.39	74.33	4.47
12.6	17.4	56.16	73.44	4.46
12.8	17.2	56.94	72.55	4.45
13.0	17.0	57.71	71.66	4.44
13.2	16.8	58.49	70.78	4.43
13.4	16.6	59.26	69.89	4.42
13.6	16.4	60.03	69.00	4.41
13.8	16.2	60.80	68.12	4.41
14.0	16.0	61.57	67.24	4.40
14.2	15.8	62.33	66.36	4.39
14.4	15.6	63.10	65.48	4.38
14.6	15.4	63.86	64.61	4.37
14.8	15.2	64.63	63.73	4.37
15.0	15.0	65.40	62.86	4.36
15.2	14.8	66.15	61.99	4.35
15.4	14.6	66.91	61.12	4.34
15.6	14.4	67.67	60.25	4.34
15.8	14.2	68.43	59.39	4.33
16.0	14.0	69.19	58.52	4.32
16.2	13.8	69.95	57.66	4.32
16.4	13.6	70.71	56.79	4.31
16.6	13.4	71.47	55.93	4.31
16.8	13.2	72.22	55.07	4.30
17.0	13.0	72.98	54.21	4.29

Table 2

Δ	E	$R_\Delta(E)$
0.4	0.4	0.00324
	0.8	0.00008
	1.2	-0.00999
	1.6	-0.02750
	2.0	-0.05300
	2.4	-0.08710
	2.8	-0.13042
	3.2	-0.18364
	3.6	-0.24753
	4.0	-0.32278
0.8	0.8	0.01314
	1.6	0.00069
	2.4	-0.04148
	3.2	-0.11798
	4.0	-0.23406
1.0	1.0	0.02068
	2.0	0.00138
	3.0	-0.06602
	4.0	-0.19094
2.0	2.0	0.08544
	4.0	0.01238
4.0	4.0	0.36530

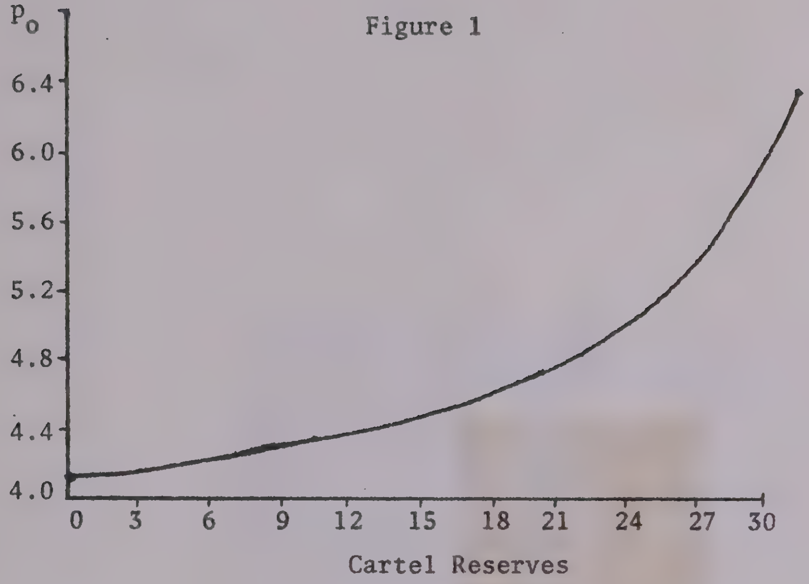

Figure 1

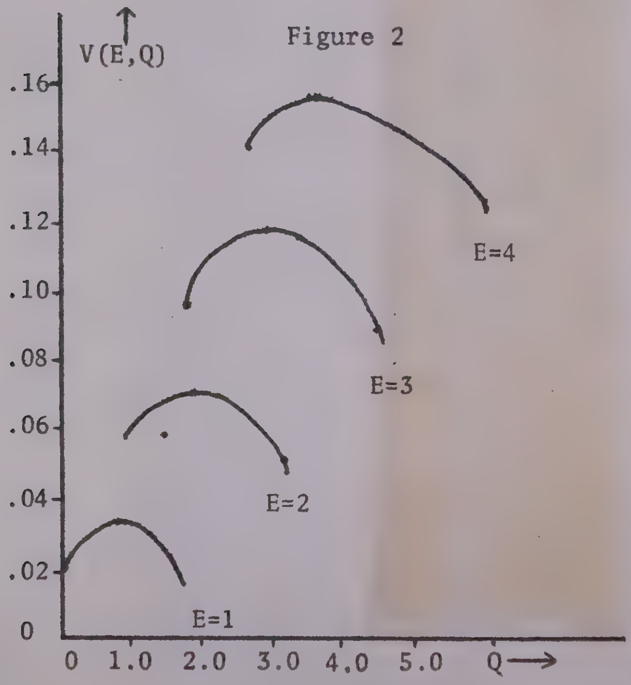

Figure 2

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